Claims

1. An optical fiber for optical amplification, characterized in that a full width at half maximum of a gain spectrum is 45 nm or more; and a maximum value of power conversion efficiency is 80 % or more.

2. A method for manufacturing a rare earth element-doped glass for use in manufacturing an optical fiber for optical amplification wherein the optical fiber has a full width at half maximum of a gain spectrum of 45 nm or more; and a maximum value of power conversion efficiency of 80 % or more, comprising:

depositing fine silica glass particles obtained by reacting a silica glass material and a co-dopant (a) obtained by reacting a raw material for the co-dopant (a) to prepare an aggregate of fine silica glass particles doped with the co-dopant (a); and

immersing the aggregate of fine silica glass particles doped with the co-dopant (a) in a solution containing the rare earth element and the co-dopant (b) for doping the rare earth element and the co-dopant (b) to the aggregate of fine silica glass particles doped with the co-dopant (a).

3. The method according to Claim 2,

wherein the co-dopant (a) is selected from an element group (A) and the co-dopant (b) is selected from an element group (B), wherein

the element group (A) is composed to the elements to control gain spectrum of the optical fiber for optical amplification, and

the group (B) is composed to the elements to control energy conversion efficiency of the optical fiber for optical amplification, and

aluminum is contained in both of at least one selected from the element group (A) and at least one selected from the element group (B).

4. The method according to Claim 3, wherein a concentration of aluminum doped in the immersing step is not more than 1.5 mass%.

5. The method according to Claim 3, wherein the concentration of aluminum doped in the depositing step is the same as or greater than the concentration of aluminum doped in the immersing step.

6. The method according to Claim 2, further comprising:

drying the aggregate of fine silica glass particles

after the immersing step;

oxidizing at least one of the rare earth element and the co-dopant element doped in the immersing step after the drying step;

dehydrating the aggregate of fine silica glass particles after the oxidizing step; and

sintering the aggregate of fine silica glass particles after the dehydrating step.

7. The method according to Claim 6, wherein the oxidization is carried out under oxygen-containing atmosphere and under a condition of increasing a temperature from nearly a room temperature to a temperature where the rare earth element and the co-dopant element are completely oxidized at a temperature elevation rate of not more than 600°C/hr.

8. The method according to Claim 6, further comprising removing a crystal water contained in at least one of the rare earth element and the co-dopant element doped in the immersing step.

9. The method according to Claim 8, wherein the crystal water removal step is carried out under an oxygen-containing atmosphere and under a condition of increasing

temperature from nearly a room temperature to a temperature where the crystal water is substantially completely removed at the temperature elevation rate of 30 to 240°C/hr then substantially maintained at the same temperature.

10. A method for manufacturing a rare earth element-doped glass used in manufacturing an optical fiber for optical amplification wherein the optical fiber has a full width at half maximum of a gain spectrum of 45 nm or more; and a maximum value of power conversion efficiency of 80 % or more, comprising:

polishing a silica glass rod so that a maximum roughness (Ry) of the outer circumferential surface is not more than 0.5μm by mechanical means;

cleaning the polished silica glass rod; and then

forming a glass layer on outer circumferential surface of the silica glass rod.

11. The method according to Claim 10, wherein

first polishing the silica glass rod so that the maximum roughness (Ry) of the outer circumferential surface is not more than 3μm by first mechanical means;

second polishing the silica glass rod so that the maximum roughness (Ry) of the outer circumferential

surface is not more than 0.5μm by second mechanical means;

cleaning the polished silica glass rod; and then

forming a glass layer on outer circumferential surface of the silica glass rod.

12. A method for manufacturing a rare earth element-doped glass used in manufacturing an optical fiber for optical amplification wherein the optical fiber has a full width at half maximum of a gain spectrum of 45 nm or more; and a maximum value of power conversion efficiency of 80 % or more, comprising:

heating a glass rod with at least partially containing crystals at a temperature higher than a glass formation temperature; and

cooling the glass rod at a temperature higher than a cooling speed in which the crystals can be extracted from the glass.

13. The method according to Claim 12, further comprising:

depositing fine particles to prepare an aggregate of fine silica glass particles; and

heating the aggregate of fine silica glass particles so as to make the fine silica glass particles into imperforate rod.

14. The method according to Claim 13, wherein the imperforation is carried out within a temperature range from 1000°C to 1500°C.

15. The method according to Claim 12, wherein

the cooling speed is expressed by the following formula:

cooling speed (°C/sec) = −178 × ln(r) + 618

wherein r is the glass rod radius (mm).

16. The method according to Claim 12, wherein

the cooling speed allowing the crystals to be generated is determined by the composition of materials and the radius of the glass rod not-crystallized is determined from the cooling speed by the following formula:

glass rod radius (mm) = EXP{-(S-618)/178}

wherein S is the cooling speed (°C/sec).

17. The method according to Claim 12, wherein the cooling speed is 400°C/sec or more.

18. The method according to Claim 12, wherein

heating is carried out after the glass rod becomes

smaller at least a part of core or cladding diameter of not more than 5mm.

19. A rare earth element-doped glass used in manufacturing an optical fiber for optical amplification wherein the optical fiber has a full width at half maximum of a gain spectrum of 45 nm or more; and a maximum value of power conversion efficiency of 80 % or more, comprising:

a glass rod having at least partially containing crystals and a diameter of not less than 5mm at least partially containing crystals, and comprising a rare earth element and an aluminum compound,

wherein the concentration of aluminum is not less than 3.5 mass%.

20. The rare earth element-doped glass according to Claim 19, wherein

all or a part of the crystals is mullite.

21. The rare earth element-doped glass according to Claim 19, wherein the crystals are a material of which overall volume is reduced by transition from a glass phase or extraction from the glass phase.

22. A method for manufacturing an optical fiber for optical amplification wherein the optical fiber has a full width at half maximum of a gain spectrum of 45 nm or more; and a maximum value of power conversion efficiency of 80 % or more, comprising:

drawing a glass rod with at least partially containing crystals.